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Heterogeneous Effects of Rural Electrification

Evidence from Bangladesh

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Abstract

Achieving universal access to electricity is one of the most important energy policy goals set by governments in the developing world. The recent empirical literature, however, paints a mixed picture about the economic viability of rural electrification. Although many studies find substantial socioeconomic benefits from rural electrification, others propose that these benefits are overstated. This paper examines the hypothesis that the magnitude and the nature of benefits associated with electrification are highly context dependent. Using a panel data of 7,018 rural households in Bangladesh for 2005 and 2010, the paper explores two underlying determinants of the heterogeneity: the quality of electricity supply and the number of years of being connected to the grid. The analysis uses an instrumental variable and propensity-score-weighed fixed-effects model to address potential endogeneity of electricity adoption. The analysis finds that power outages have a negative impact on almost all development outcomes considered, while some benefits of electrification accrue only over the long run. The overall gain from expanding access to and improving reliability of electricity supply in Bangladesh is estimated to be US$2.3 billion a year.

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Heterogeneous Effects of Rural Electrification: Evidence from Bangladesh[1]

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JEL: D6, Q4, R2

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I. Introduction

Around the world, over 1.2 billion people still lack access to grid electricity and globally, about 84 percent of those without electricity live in the rural areas (IEA 2016). Rural electrification has been widely recognized as a key driver for alleviating poverty and boosting economic development, and has been ranked highly on the agenda of governments, nongovernmental organizations (NGOs) and international development agencies. Recently, a growing amount of research seeks to empirically assess the effects of rural electrification on micro-level development outcomes. The recent literature, however, paints a somewhat mixed picture about the economic viability of rural electrification. While many studies find substantial benefits from electrification on income, labor supply and education results, others suggest that these benefits may be overstated.

For example, Burlig and Preonas (2016) find only modest impact of rural electrification on labor participation and no effects on asset ownership, housing stocks and village-level public good provision in India. Using a randomized field experiment in India, Aklin et al. (2017) find no evidence for changes in spending, business creation, time spent working or studying and other indicators of socioeconomic development within a year of electrification. Also using an experimental approach, Lee, Miguel and Wolfram (2016) suggest that rural electrification in Kenya may reduce social welfare as the costs of grid expansion significantly outweigh its benefits. Bensch, Kluve, and Peters (2011) find no effect of rural electrification on income and children's home study using data from Rwanda. Among papers that reported positive net benefits of electrification, findings on magnitudes of the benefits are wide-ranging (Table A1).

In this paper, we argue that there are at least two explanations for the lack of conclusive evidence in the literature. We hypothesize that the size and type of benefits electrification can bring about are context-dependent. Electricity leads to improved living standards through services provided by electrical appliances. The benefits are likely to be low if the "connected" households do not receive an adequate level of services due to unreliable electricity supply. Power outages are particularly a concern in developing countries where businesses report at least 20 hours of electricity outages a month,[2] and millions of households receive only a few hours of electricity a day. Both technology failures and systematic power cuts during periods of power shortages cause frequent and long hours of blackouts in developing countries. Poor quality of electricity supply could constrain and even discourage the productive use of electricity by households and businesses.

[2] World Bank Enterprise Survey.

The second factor that could contribute to the heterogeneous effects of electrification is the duration households have been connected to the electric grid. While some basic benefits such as more efficient lighting can be achieved almost immediately upon electrification, other development impacts accrue only over the long run. For example, improved lighting may allow businesses to be open more hours in the evening. This would lead to more economic activities and contribute to income growth in the long term. With improved income, households can afford more time- and labor-saving electric devices, and to engage in more income generating activities. Once a virtuous cycle kicks in, the accumulated benefits of electrification could be positively correlated with the number of years a household has been connected to the grid during an extended period.

Using data from a panel survey of 7,018 rural households for 2005 and 2010 in Bangladesh, we examine the spatial and temporal heterogeneity of the effects of rural electrification. We use household's distance to the nearest electric pole as an instrument variable and a two-stage propensity-score-weighted fixed effects model to address potential endogeneity of treatment which could derive from nonrandom expansion of the electricity network and nonrandom adoption of electricity by households.

We find that the length of daily power outages has a strong negative impact on almost all development outcomes considered. For example, a one hour increase in power outages per day is associated with a 5.9 percent increase in kerosene consumption and 0.3 percent reduction in annual income. When power outages last longer than 21 hours a day, there is effectively no difference between the electrified and the non-electrified households. On the other hand, the benefits of electrification increase with years of exposure to grid electricity, albeit with a declining rate. For example, each additional year of being connected to the grid is associated with a 7.8 percent reduction in kerosene consumption and a 1 percent increase in annual income. Labor market benefits of electrification seems to take the longest time to materialize.

Overall, we find that electrification in Bangladesh has brought substantial benefits to rural households as evidenced by increased income, time spent in study, and labor force participation, as well as higher women's empowerment. Even without accounting for the benefits associated with better education and empowerment outcomes, the potential gain from providing universal access to electricity and improving reliability of electricity supply in Bangladesh could reach US$ 2.3 billion a year.

We also find that electrification disproportionally benefits women and girls. After gaining access to electricity, girls' study time on average increases 0.47 hours a day while women's labor force participation increases 2.3 percentage point a year. On the other hand, no statistically significant effects are observed for boys' study time or men's labor force participation.

Electrification could lead to divergence or convergence of living standards. On one hand, richer households are typically early adopters of electricity and can afford a wider range of electric appliances to make productive use of electricity. On the other hand, there are spillover effects from electrification from which poor households can benefit. For example, benefits from television, better lighting, or mobile charging can be easily shared with unelectrified neighbors. In addition, as the marginal return to electrification declines over time, poorer households who are connected to the grid may catch up at a later stage. Using a quantile regression approach, we explore the distributional impacts of rural electrification across income groups. We find that the marginal effects of electrification on income or expenditure growth for higher-income households is monotonically higher than that for lower-income households. The results suggest that richer households still benefit more from electrification than poorer households during the time span covered by the evaluation.

Our findings suggest that while broadening electricity access is important for improving the wellbeing of rural households, merely providing a connection is not sufficient to spur economic growth, especially when the quality of electricity supply is poor. To achieve long-term and inclusive benefits from electrification, governments would need to exert long-term efforts to improve the reliability of the electric grid and to implement complementary policies to encourage productive use of electricity, especially among poor households. Our results also show that the magnitude of benefits that can be reaped from electrification is very much context-dependent – an issue that should not be overlooked while studying the effects of rural electrification.

The rest of the paper proceeds as follows: Section II provides a brief background of rural electrification in Bangladesh. Section III presents data and descriptive analysis. Section IV describes the empirical strategy. Section V reports the estimated heterogeneous effects of rural electrification. Section VI estimates the distributional benefits of electrification across income and expenditure quantiles. Section VII discusses policy implications and concludes the paper.

II. Rural Electrification in Bangladesh

Bangladesh is an agricultural country with a population of about 161 million. In 2014, about 66 percent of the population lived in the rural area and only about 50 percent of the rural households had access to grid electricity. From its beginning, the Government of Bangladesh has been committed to extending electricity services to rural areas to promote social and economic development. In 1977, the government established the Bangladesh Rural Electrification Board (BREB, formerly known as REB) with a mandate to expand electricity supply in rural areas. BREB is responsible for planning and implementing all investments in rural electric grid infrastructure. It also organizes prospective electricity consumers of a selected area into rural electric cooperatives called *Palli Bidyut Samity* (PBS). A PBS is an autonomous organization that owns and operates a rural distribution system within its franchise area. A PBS typically covers a geographic area of about 700-800 square miles and serves around 60,000 to 100,000 residential customers. BREB provides technical assistance and finances to PBS, liaises between PBS and the bulk power suppliers, and oversees the performance of PBS.

Since its inception, BREB has made important strides in expanding rural electrification in Bangladesh. The first PBS was established in 1980 in Dhaka. Since then, a total of 77 PBSs have been created, serving more than 13 million residential customers in some 58,000 villages all over the country. Consequently, the access rate to grid electricity in rural areas has grown from less than 10 percent in 1977 to about 51 percent in 2014.

In recent years, the government has also partnered with NGOs and international organizations to promote off-grid options, particularly solar home systems, to provide electricity to remote villages where grid electrification is difficult and expensive. Since 2009, more than 50,000 solar home systems have been installed every month in Bangladesh, making it the fastest growing market for solar home systems in the world. In this paper, we focus on estimating the effects of grid electricity only.

Despite considerable growth in electrification, access to electricity in Bangladesh still ranks among the lowest in the world. Even for those connected to the grid, electricity supply is uneven and irregular due to fuel shortages and power generation capacity constraints, both of which contribute to frequent power cuts. Rural areas are especially affected by power shortages. Our data suggest that in 2005 more than 50 percent of the rural households with electricity faced a power outage of 8 hours per day or more (Table 1). The average duration of power outages was 9.8 hours per day.

To address generation shortages and to further increase access to electricity, the government has adopted multiple strategies that include energy conservation, load management, promoting private investment, and improving sector governance and efficiency. The ultimate objective is to provide universal access to reliable electricity by 2021.

III. Data and Descriptive Analysis

A. Data

Under the Rural Electrification and Renewable Energy Development Project (RERED), the World Bank has been supporting Bangladesh's efforts to increase access to electricity in rural areas through both grid and off-grid options since the mid-1990s. This study is based on two rounds of World Bank-sponsored household survey intended to assess the impacts of the RERED project. The surveys were carried out under the auspices of BREB. The first-round survey, carried out in 2005, has a nationally representative sample of 20,900 households from about 1,300 villages. The survey covers a wide geographic area, including 45 of 70 PBS, operated by BREB. Details of the survey design can be found in Khandker, Barnes and Samad (2013).

A follow-up survey in 2010 retraced 16,236 households from the original population. A stratified random sample of 7,352 households was then drawn based on village level attrition rate – a village is selected if at least 10 and no more than 25 original households remain in the panel. After data cleaning 7,018 households representing all 45 original PBS are used for the analysis.

Both rounds of surveys contain detailed questions on households' social and economic characteristics, income, expenditure, and energy use patterns, such as monthly electricity consumption, the status of grid connection, and households' appliance ownership. The 2005 survey also contains information on quality of electricity services. Specifically, households were asked to report daily average duration of electricity supply in hours.

B. Descriptive analysis

Table 2 describes the geographic distribution and electricity access rate of the surveyed population. The sample size of each division is. in general proportional to the electrification rate of that division. Rajshahi division accounts for the largest share of the sample, followed by Chittagong division. Barisal division has the lowest electrification rate and the smallest sample size. The household electrification rate has gone up significantly over the 5-year period between the two surveys, from 32 percent to 46.7 percent on average. Across the divisions, Sylhet and Chittagong have undergone the largest expansion of electric grid Households reporting having access to grid electricity increased from 35.1 to 54.5 percent in Sylhet, and from 35.5 to 53.6 percent in Chittagong, between 2005 and 2010.

Table 3 compares mean outcomes of households and individuals by electrification status. It shows that households with access to grid electricity on average consume less kerosene than off-grid households in both survey years, and the differences are statistically significant. Grid-connected households are also better off than their off-grid counterparts in terms of total income and expenditure. Specifically, for households with access to electricity, per capita income is 29 and 26 percent higher, and per capita expenditure is 14 percent and 24 percent higher than those of households without electricity in 2005 and 2010, respectively. Notably, off-grid households have a higher per capita farm income in 2010. It is possible that while grid-connected households have moved from farm to non-farm activities over the years, off-grid households have maintained and expanded farm activities.

At the individual level, children in electrified households spend longer hours studying. For example, in 2010, girls in households with access to electricity studied about 2.4 hours per day, compared to 2 hours spent on study per day by girls who lived off-grid. Labor force participation among individuals was also higher in households with electricity in 2005, although the results were opposite in 2010. Finally, better empowerment outcomes are observed among women with access to electricity. For example, women are more likely to own income generation activities and have more decision-making power if they reside in households with access to electricity. While the differences are not statistically significant in 2005, they become much larger and statistically significant in 2010.

Table 4 describes mean outcomes of electrified households by average daily electricity availability based on 2005 survey data.[3] Results of five groups of households are compared – those facing daily outages up to 5 hours, between 6 and 10 hours, 11 to 15 hours, 16 to 20 hours, and above 21 hours or more. There is generally a positive correlation between hours of power outages and volume of kerosene consumption, and negative correlation between length of the outages and income and expenditure, study hours, labor force participation rate and women's empowerment. Also noticeable is the fact that when outages are longer than 21 hours per day, there are almost no distinguishable differences between unelectrified and electrified households.

Table 5 reports mean outcomes of grid-connected households in 2010 based on their duration of exposure to grid electricity. Again, five groups of households are considered – those connected to electricity grid for up to a year, between 2 and 5 years, between 6 and 10 years, between 11 and 15 years, and 16 years or more. The findings reveal a positive correlation between the duration of exposure and household and individual socioeconomic outcomes. Notably, kerosene consumption goes down almost immediately after a household gains access to grid electricity. But other benefits manifest themselves only gradually over time. For example, increase in income and expenditure, and hours of study by children are only observed

[3] The 2010 survey did not include questions on daily duration of power outages. So, all analyses related to the effects of quality of power supply are based on 2005 survey data.

among households who have been connected to the grid for more than a year, while growth in labor force participation is only observed among households who have been connected for more than 11 years.

Table 6 shows ownership levels for different types of appliances of the five groups of households by duration of grid connectivity. Household who have been connected to the grid for a longer period clearly own more appliances. For example, the proportion of households who own a refrigerator is 4.4 percent among households who have gained connection for less than a year. It reaches 37 percent for households who have been connected to the grid for more than 16 years.

Tables 5 and 6 present suggestive evidence on heterogeneous returns to rural electrification. It is possible that the households that were well-off to begin with adopted electricity earlier and can afford a wider range of appliances than those who were poor. Indeed, as shown in Figure 1, duration of connection in 2010 is positively correlated with households' income in 2005.[4] For example, the duration of connection of households in the 10th income decile is about four times that of those in the bottom decile. In the following section, we formally address the endogeneity issue to identify the causal effects of rural electrification conditional on the two dimensions of heterogeneity discussed above.

IV. Empirical Strategy

We examine the effects of electrification as depending on the reliability of electricity supply, and the length of time of being connected to grid, using the following conditional outcome equation:

$$Y_{it} = \beta X_{it} + \gamma E_{it} + \varphi(E_{it} * D_{it}) + \delta T_t + \mu_i + \varepsilon_{it} \qquad (1)$$

where, Y_{it} denotes the outcome variables of interest of household *i* in year *t* (t=0 for 2005, and 1 for 2010); X_{it} is a vector of observable household- and community-level characteristics, including age, gender and education level of household's head, the number of adult males and females in the household, the amount of household land asset, housing structure, household's access to piped water or tube well. We also control for whether a household owns solar home systems, an important alternate source of electricity in Bangladesh. At the village level, we control for village price of alternate fuels, including firewood, kerosene and liquefied petroleum gas (LPG). E_{it} is a dummy variable measuring households' electrification status. E_{it} equals 1 if the household has access to electricity, and 0 otherwise. D_{it} denotes the contextual variables,

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[4] On the other hand, we did not find a correlation between households' income and exposure to power outages. This is probably because power cuts are widespread in the rural areas, and hence, both rich and poor households are equally affected.

including the average duration of electricity outages each day measured by hours, and the number of years elapsed since the household was first connected to the grid.

T_t is year fixed effects capturing year specific shocks that are consistent across all households. μ_i represents unobserved time-invariant household and village-level determinants of the outcomes. ε_{it} is the error term. $\beta, \gamma, \varphi,$ and δ are unknown parameters to be estimated. The aggregate treatment effect of electrification is measured by $(\gamma + \varphi D_{it})$. The hypothesis is that as D_{it} changes, the observed effects on the outcomes attributable to electrification would also change.

The challenge for estimating equation (1) is that unobserved household and community-level characteristics (μ_i) may be correlated with both outcome variables (Y_{it}) and the treatment (E_{it}) and/or contextual variables (D_{it}). For example, government may choose to roll out electrification projects in areas with greater growth potential; when electricity becomes available at the village level, more resourceful households are more likely to adopt electricity. Because μ_i cannot be directly controlled for, an OLS estimation of equation (1) would be biased because of omitted variable bias.

If each household is observed more than once in the sample, a household-level fixed-effects (FE) model can be used to eliminate time-invariant unobserved factors. Specifically, we take the difference of equation (1) over the two periods (period 0 for 2005 and 1 for 2010) which yields:

$$Y_{i1} - Y_{i0} = \beta(X_{i1} - X_{i1}) + \gamma(E_{i1} - E_{i0}) + \varphi(E_{i1} * D_{it} - E_{i0} * D_{i0}) + \delta(T_1 - T_0) + (\mu_i - \mu_i) + (\varepsilon_{i1} - \varepsilon_{i0})$$

$$\text{or} \quad \Delta Y_i = \beta \Delta X_i + \gamma \Delta E_i + \varphi \Delta(E_i * D_i) + \delta \Delta T + \Delta \varepsilon_i \qquad (2)$$

Since there is no unobserved component, equation (2) gives an unbiased estimate of the treatment effect, given that the assumption of the time-invariance of μ_i holds.

However, a simple FE estimation of equation (1) will still be biased if the unobserved determinants of outcome variables change over time and are correlated with E_{it} , or D_{it}, or both. For example, the perceived benefits of electrification may evolve over time. This in turn will affect households' decision to adopt and utilize electricity dynamically. In this case, equation (1) can be rewritten as:

$$Y_{it} = \beta X_{it} + \gamma E_{it} + \varphi(E_{it} * D_{it}) + \delta T_t + \mu_i + \eta_{it} + \varepsilon_{it} \qquad (3)$$

where η_{it} is the time-varying unobserved heterogeneity. Taking the difference of equation (3) between the two-time periods gives:

$$\Delta Y_i = \beta \Delta X_i + \gamma \Delta E_i + \varphi \Delta(E_i * D_i) + \delta \Delta T + \Delta \eta_i + \Delta \varepsilon_i \qquad (4)$$

As equation (4) shows, the unobserved factor is not eliminated, and hence, a simple FE estimation of equation (3) will still be biased.

To address the potential endogeneity concern, we use two approaches: instrumental variable (IV) approach and propensity score-weighted fixed-effects model. An instrumental variable must satisfy two conditions: it is directly correlated with the treatment variable but not with the outcome variables; the outcome variables are only indirectly affected through its impact on the treatment variables. In this study, we explore the idea of using connection cost as possible instruments for electricity adoption. High initial charges households must pay to be connected to the grid are often identified as a significant obstacle to electricity adoption in developing countries (Winkler et al. 2011). In Bangladesh, like in many other countries, households must pay a fixed fee to be connected to the electric network, and the average connection cost per household was Taka 2800 (US$40) or about 5 percent of annual total household expenditure based on a 2006 study (Mainuddin 2006). The connection cost varies with a household's proximity to the nearest electric pole. The closer the distance, the lower is the cost. If a household is located within 100 feet of the nearest pole, connection is given free of cost. Free or low connection offers a strong incentive for households to adopt grid electricity but it does not otherwise affect the outcomes of interest. Therefore, similar to Khandker, Barnes and Samad (2013), we use the following choice variable as an instrument to capture exogenous variation in electrification status:

Z = 1 if household is located within 100 feet of an electric pole.

= 0 otherwise.

We also interact Z with household exogenous characteristics, including age, gender, and education of the households' head to create additional instruments. Data on electricity availability are only reported for 2005, and so, IV method is combined with village-level fixed effects and implemented using the cross-sectional data of 2005 to estimate the heterogeneous effects of electrification caused by variation in electricity reliability.

To examine how years of connection affects the accumulated benefits of electrification, we use propensity score-weighted fixed effects in a panel setting. Heckman (1981), Chamberlain (1984), and Arulampalam, Booth, and Taylor (2000) show that unobserved heterogeneity is often correlated with initial conditions. Based on the insights from the literature, we estimate a propensity-score-weighted fixed-effects model in two stages by controlling for initial household- and village-level characteristics. In the first stage, we estimate a household's probability of being connected to the grid as a function of household and community-level exogenous characteristics observed in year 2005. In the second stage, the impact of electrification is estimated using a weighted household-level fixed-effects model, with the weight being a function of the predicted probability, i.e. the propensity score (*p*). Specifically, following Hirano, Imbens, and Ridder (2003), for households that are connected to the grid, the weight equals 1; for households that are not connected to the grid, the weight equals $p/(1 - p)$, where *p* is the propensity score. The idea is that off-grid households that are closer to grid-connected households in terms of initial characteristics would receive a higher weight in the regression.

Finally, we expect the return to electrification will increase over time until it reaches a plateau. To account for the possibility of a diminishing return to electrification, we include a square term of the total years of electricity connection (D_{it}) in equation (1):

$$Y_{it} = \beta X_{it} + \varphi(E_{it} * D_{it}) + \rho\left(E_{it} * D_{it}^2\right) + \delta T_t + \mu_i + \varepsilon_{it} \qquad (5)$$

V. Results

To assess impacts of rural electrification on households' welfare, we consider a broad range of social and economic outcomes, ranging from the consumption of traditional fuel to income, expenditure, education, employment, and women's empowerment. In this section, we first discuss the differential effects of rural electrification due to heterogeneity in reliability of electricity supply and the length of time exposed to grid electricity. We then explore their implications for the distributional benefits of electrification.

A. Reliability of electricity supply

Table 7 reports estimation results of equation (1) with the contextual variable being hours of electricity supply per day. Columns (1) and (2) report estimating results from a simple OLS model and an IV model, respectively. Column (3) reports aggregate mean effects of electrification based on the IV model.

Table 7 shows that electrification brings multiple benefits, but the size of the benefits could be significantly reduced when electricity supply is unreliable. In addition, the effects of electrification (conditional on hours of electricity availability) estimated from the IV model are generally greater than those from the OLS model, suggesting potential endogeneity of the electrification variable. In the following, estimations from the IV model (columns (2) and (3)) are the preferred results to be discussed.

The first immediate benefit of gaining access to electricity is the reduction of kerosene consumption. Kerosene lamps are the primary source of lighting in households without electricity. Kerosene lamps not only produces much inferior light in terms of lumens per square meter than electric bulbs, they are also a major source of indoor air pollution and ambient black carbon emission. Once connected to the grid, households' kerosene consumption is on average reduced by 73 percent conditional on prevailing electricity availability in the sample. On the other hand, the finding also reveals a positive correlation between kerosene consumption and power outages. As shown in the first panel of Table (8), each one hour increase in the duration of blackouts is on average associated with a 6 percent increase in kerosene use.

After obtaining access to grid electricity, households also experienced significant increase in per capita income, on average by 17 percent during 2005-2010. The growth in income seems to be contributed mostly by an increase in nonfarm income, suggesting that electricity may have provided opportunities for more diversified economic activities in rural areas. Without electricity outages, nonfarm income would on average go up by 34 percent over the sample period. Farm income is also positively correlated with electrification but the coefficient is not statistically significant. Power outages dampen the positive effects of electrification on households' income, especially for nonfarm income. As shown in the second panel of Table (8), every one hour increase in power outages per day is correlated with a 0.3 percent reduction in per capita total income, and 0.6 percent reduction in per capita nonfarm income.

Corresponding to income increase, following grid connection, households also increased non-food spending, on average by 21 percent over the sample period. As a result, total per capita expenditure increased by 12 percent. Meanwhile, every one hour increase in daily power outages is associated with a 0.8 percent reduction in households' nonfood expenditure. There is no statistically significant correlation between electrification and food expenditure.

Women and girls are traditionally responsible for household chores. Electrification can help free up the time women and girls spend on domestic chores so they can engage more in productive activities such as education, employment and social participation. Indeed, as shown in the third and fourth panels of Table (8), we find that getting access to grid electricity increases the time spent on studies on average by 0.47 hours per day among girls. It also increases women's labor force participation by 2.3 percentage points, while no such effects are observed for by boys' study time or men's labor force participation. However, power cuts again mitigate these positive impacts of electrification. Every one hour increase in power outages per day reduces girls' daily study time by 0.11 hour.

We explore several additional metrics to examine the impact of electricity access on women's empowerment. We find that getting access to electricity increases women's decision-making powers.

Women who have access to electricity are more likely to decide alone on children's health care, and decide alone on the use of own income. Grid electricity also facilitates increased access to information: women who have access to grid electricity spent more time watching TV or listening to radio.

B. Time length of being connected to the grid

Table 8 reports the joint effects of rural electrification and the length of time connected to the grid. Columns (1) and (2) are estimations based on a simple household-level fixed-effects model, and a propensity-score-weighted fixed-effects model, respectively. Results from the two models are slightly different. The propensity-score-weighted fixed-effects model is again our preferred specification.

The time span of being connected to the grid has a positive impact on most of the household and individual outcomes. For example, given the average length of time connected to the grid at 10.5 years in 2010, each additional year of exposure to grid electricity reduces households' kerosene consumption by 7.8 percent. A one year increase is also on average associated with a one percent increase in total per capita income, 4.1 percent increase in nonfarm income, a 1.1 percent increase in per capita total expenditure, a 2.3 percent increase in nonfood expenditure, 0.04 and 0.05 hour of daily increase in time spent on studies by boys and girls, respectively, and increased women's decision-making power. In addition, the squared term of the time variable is statistically significant for kerosene consumption, per capita total income and farm income, and women's time spent in watching TV or listening to radio, and is of opposite sign of that of the time variable, indicating diminishing marginal returns to electrification on these outcomes. Results are robust when the square term of the time variable is not included, as shown in Table A2.

Notably, we did not observe similar effects of the time variable on labor force participation. As Table 5 shows, distinctly better employment outcomes are only observed among groups that have been connected to the grid for 11 years or longer. The lack of significant correlation between labor force participation and time span of grid connection could be explained by the fact that most of the households in the sample have been connected to the grid for less than 10 years in 2010.

To further describe the heterogeneous effects of electrification due to variation in the length of time of grid connection, we predict outcome variables assuming households have been connected to the grid for one year and for 10 years. Table 10 shows substantial variation in the predicted individual- and household-level effects. For example, reduction in kerosene consumption ranges from 7.7 percent to 60 percent, total per capita income growth ranges from 4 percent to 36 percent, time spent on studies by girls ranges from 0.05 to 0.33 hours per day, because of changes in grid duration length from one to 10 years.

VI. Distributional Benefits of Electrification

Since appliance ownership plays an important role in making productive use of electricity, wealthier households, who can afford a more diversified portfolio of appliances, may be able to reap more benefits from electrification than poorer households. For this reason, electrification could lead to divergence of income growth, at least initially. On the other hand, poorer households can catch up as they benefit from potential positive spillover effects (Dinkelman, 2011; Van de Walle et al. 2015) and can acquire more types of electric appliances and tools over time. In this section, we estimate a quantile regression model to examine whether the divergence or catch-up effect dominates and how the benefits of electrification vary by household initial income status.

Following Koenker and Bassett (1978), the quantile regression model is described as follows:

$$Y_i = \beta_\theta X_i' + \varepsilon_{\theta i} \quad (6)$$

Similar to the conditional mean of a linear regression E(Y/X), the conditional quantile function can be expressed as:

$$Q_\theta(Y_i|X_i) = \beta_\theta X_i', \theta \in (0,1) \quad (7)$$

where $Q_\theta(Y_i|X_i)$ denotes the quantile θ of the outcome Y_i conditional on the vector of covariates X_i. The quantile θ is the value of Y_i which divides the data into two proportions – θ on one side and (1– θ) on the other. While OLS solves the outcome equation by minimizing the term $\sum_i \varepsilon_i^2$, quantile regression minimizes the following term:

$$Q(\beta_i) = \sum_{i:Y_i \geq \beta X_i'} \theta | Y_i - \beta X_i' | + \sum_{i:Y_i < \beta X_i'} (1-\theta) | Y_i - \beta X_i' | \quad (8)$$

The parameters in equation (6) can be estimated semi-parametrically using linear programming methods (Buchinsky 1998). To account for possible heteroskedasticity in the error term, the variance-covariance matrix of coefficients can be estimated using bootstrapping. The quantile's coefficients can be interpreted as the partial derivative of the conditional quantile of Y_i with respect to X_i.

For panel data, we can express the quantile function for electricity intervention as follows:

$$Q_\theta(Y_{it}|X_{it}, E_{it}, \epsilon_{it}) = \alpha_\theta X_{it} + \beta_\theta E_{it} + \varepsilon_{it} \quad (9)$$

where E_{it} is the electrification dummy, the subscript *t* refers to survey round (*t*=0 for 2005 and 1 for 2010) and the error term ε_{it} subsumes unobserved household and village-level factors. Unlike the case of OLS, we cannot take the first-difference of equation (9) for two periods to implement fixed effects for quantile regression, because quantiles are not linear operators. That is,

$$Q_\theta(Y_{i1} - Y_{i0}|X_i, E_i, \varepsilon_i) \neq Q_\theta(Y_{i1}|X_{i1}, E_{i1}, \varepsilon_{i1}) - Q_\theta(Y_{i0}|X_{i0}, E_{i0}, \varepsilon_{i0})$$

To overcome this problem, we follow Gamper-Rabindran, Khan, and Timmins (2010), which specify the unobserved effect ε non-parametrically as an unknown function φ(.) of the covariates *X*:[5]

$$\varepsilon = \varphi(X_{i0}, X_{i1}) \qquad (10)$$

Substituting equation (10) in equation (9), we take the first difference to get:

$$Q_\theta(Y_{i1}|X_{i1}, E_{i1}, \varepsilon_{i1}) - Q_\theta(Y_{i0}|X_{i0}, E_{i0}, \varepsilon_{i0}) = \alpha_\theta(X_{i1} - X_{i0}) + \delta_\theta(E_{i1} - E_{i0}) \qquad (11)$$

or, $Q_\theta \Delta Y_i = \psi_\theta \Delta Z_i + \delta_\theta \Delta E_i$

Gamper-Rabindran, Khan, and Timmins (2010) show that the quantile regression can be estimated using a two-step procedure. First, based on equation (11), $Q_\theta(Y_{it}|X_{it}, E_{it}, \varepsilon_{it})$ is nonparametrically estimated for each period, with *X* and *E* entering linearly in the equation. Second, the differenced fitted values from the estimations $[\widehat{Q_\theta}(Y_{i1}|X_{i1}, E_{i1}, \varepsilon_{i1}) - \widehat{Q_\theta}(Y_{i0}|X_{i0}, E_{i0}, \varepsilon_{i0})]$ are regressed on the differenced regressors $(X_{i1} - X_{i0})$ and $(E_{i1} - E_{i0})$, since the proxies for the fixed effects are now eliminated from the estimation.

Table 10 reports the marginal effects of electrification on income and expenditure growth by households' income and expenditure quantiles. A distinct pattern emerges from the results: as we move from lower to higher quantiles, returns to electrification in terms of income and expenditure growth monotonically increase. In fact, no statistically significant income growth is observed among households below the 60th percentile of the income distribution. While expenditure increase occurs across the board, growth in expenditure is only 3.8 percent for households in the lowest income quintile compared to 10.6 percent for households in the highest income quintile. Consistent with findings reported by Khandker, Barnes and Samad (2012), on average, wealthier households still benefit more from electrification than poorer households in terms of income and expenditure growth as of 2010.

[5] Abrevaya and Dahl (2008) apply a similar approach based on the correlated fixed-effects model of Chamberlain (1984), where the fixed effect is specified as a parametric (linear) function of the covariates X.

VI. Conclusion

Achieving universal access to electricity is one of the most important energy policy goals set by governments in the developing world. Recent empirical literature on the development effects of electrification however reported vastly different findings. They range from negative net benefits to significant positive gains from electrification. In this paper, we explain the conflicting evidence reported in the literature by exploring two underlying determinants of the magnitude of electrification benefits: the quality of electricity supply and the time span of being connected to the grid.

Using a panel data set of 7,018 households in Bangladesh for 2005 and 2010, we examine a wide range of household and individual socioeconomic outcomes after gaining access to the electric grid, including kerosene consumption, per capita income and expenditure, time spent on studies by boys and girls, labor force participation among men and women, and women's empowerment. We use both an instrumental variable approach and a two-stage propensity-score-weighted fixed-effects model to address potential endogeneity associated with the nonrandom adoption of electricity.

We find that gains from electrification are significantly positively correlated with the reliability of electricity service and the time span of being connected to the grid. Taking the example of the impact electrification has on income growth, every one hour increase in daily power outages is associated with a 0.3 percent reduction in annual income, while every one additional year of grid connection is associated with a one percent increase in income. The average treatment effect of electrification on per capita annual income growth is estimated to be 17 percent. Like in many other developing countries, power shortages severely constrain business and households' use of electricity in Bangladesh, where average duration of power outages is 9.8 hours a day in 2005. Reducing power outages is estimated to generate income gains of US$ 486.3 million per year. Accounting for income growth alone, the total potential benefits from improving reliability and achieving universal access to electricity could reach US$2.3 billion a year in Bangladesh.

Using a semiparametric quantile regression approach, we also estimate the distributional treatment effects of electrification. We find that the benefits of grid connection monotonically increase with households' initial income status. For example, the expenditure gain from gaining access to grid electricity is about 10.6 percent for the households in the 80th expenditure quantile whereas it is only about 3.8 percent for the households in the 20th expenditure quantile. Although rich and poor households are equally affected by power outages, rich households are likely to be connected to the grid for a much longer time and own a wider range of electric devices to enable more productive use of electricity.

Findings of this paper underscore the importance of providing adequate and reliable power in addition to expanding grid connection. Complementary policies are also needed to encourage income generating activities from the use of electricity to maximize the development impact of electrification. Finally, we show that a greater focus on the heterogeneous effects of electrification is needed to have a better understanding of the effectiveness of rural electrification interventions.

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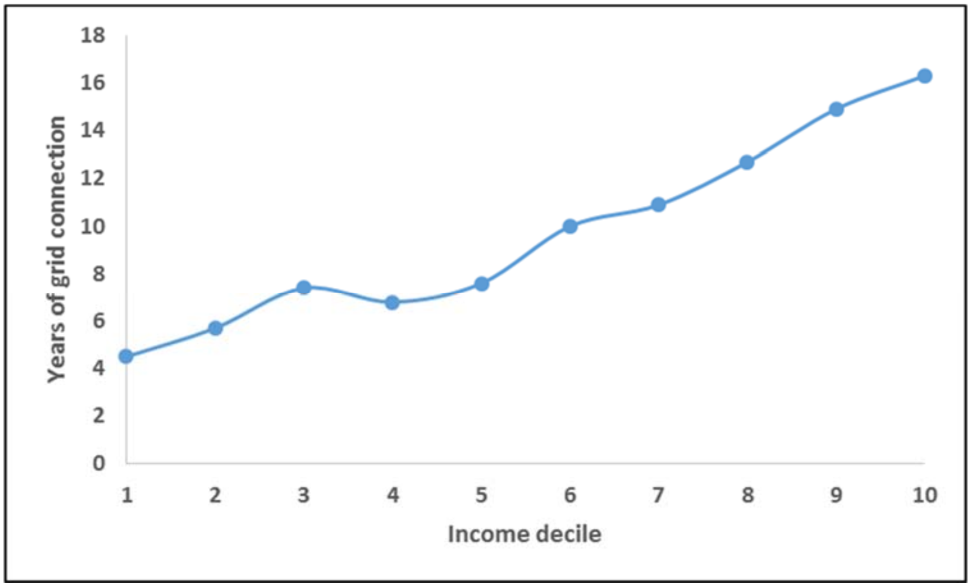
Figure 1. Relationship between household income and duration of grid connection



Source: BREB household survey, 2010

Table 1 Length of daily power outages (N=9,784)

Outage duration	Share of households (%)
No outage	*1.0*
Outage duration 1-4 hours/day	6.7
Outage duration 5-8 hours/day	40.4
Outage duration 9-12 hours/day	27.2
Outage duration 13-16 hours/day	14.5
Outage duration 17-20 hours/day	5.0
Outage duration 21+ hours/day	5.2
Average outage duration for all households (hours/day)	9.8

Source: BREB household survey, 2005

Table 2 Geographic distribution of survey sample by year

Division	Number of HHs	Electrification rate (%)	
		2005	**2010**
Barisal	718	17.1	29.2
Chittagong	1,427	35.5	53.6
Dhaka	1,066	36.8	49.3
Khulna	1,219	34.1	47.2
Rajshahi	1,505	28.7	40.5
Sylhet	1,083	35.1	54.5
Total	7,018	32.0	46.7

Source: BREB household surveys, 2005 and 2010

Table 3 Household and individual outcomes by electrification status

Outcome variables	2005		2010	
	HHs with electricity	HHs without electricity	HHs with electricity	HHs without electricity
Consumption of traditional fuel				
Kerosene consumption (liters/month)	1.95**	3.29	1.82**	2.63
	(1.73)	(3.29)	(2.72)	(1.92)
Economic outcomes				
Per capita farm income (Tk./month)	531.6*	485.4	497.4**	776.3
	(1,266.1)	(709.2)	(1,082.4)	(776.3)
Per capita nonfarm income (Tk./month)	1,271.5**	913.3	1,938.5**	1,162.8
	(1,420.2)	(1,039.6)	(6,561.1)	(3,170.2)
Per capita total income (Tk./month)	1,803.1**	1,398.7	2,435.9**	1,939.2
	(2,373.3)	(1,124.3)	(6,599.6)	(3,470.2)
Per capita food expenditure (Tk./month)	683.7**	625.0	626.2**	593.0
	(269.7)	(244.3)	(275.5)	(277.9)
Per capita nonfood expenditure (Tk./month)	367.4**	297.9	607.7**	406.4
	(313.2)	(293.2)	(2,437.2)	(632.2)
Per capita total expenditure (Tk./month)	1,051.2**	922.9	1,233.9**	999.4
	(479.8)	(430.1)	(2,492.5)	(758.1)
Education outcomes				
Time spent in studies by boys (hours/day)	2.19**	1.88	2.41**	2.23
	(2.06)	(1.99)	(1.73)	(1.71)
Time spent in studies by girls (hours/day)	2.48**	2.08	2.37**	2.03
	(2.10)	(1.99)	(1.82)	(1.78)
Employment outcomes (age 15-65)				
Labor force participation by men	65.9*	61.2	74.0**	79.2
	(19.8)	(21.4)	(49.8)	(48.7)
Labor force participation by women	31.7**	26.0	41.2**	44.5
	(41.2)	(40.0)	(43.2)	(38.8)
Women's Empowerment (age 15-49)				
Women own income generation activities	12.5	11.7	21.0**	17.9
	(33.0)	(32.2)	(40.7)	(38.3)
Women's time spent in watching TV or listening to radio (minutes/day)	16.1**	6.6	63.5**	19.1
	(41.3)	(24.9)	(64.0)	(19.5)
Women can decide alone on children's healthcare (%)	22.7	23.0	82.8**	80.4
	(41.9)	(42.1)	(32.7)	(39.7
Women can decide alone on the use of own income	56.2	56.8	87.5**	85.7
	(49.6)	(49.5)	(33.0)	(35.0)

Note: Monetary figures are CPI-adjusted (2005=100). Figures in parentheses are standard deviations. * and ** refer to statistical significance of the difference in outcomes between electrified and non-electrified households at 10 percent and 5 percent level (or better), respectively.
Source: BREB household surveys, 2005 and 2010

Table 4 Household and individual outcomes by length of daily electricity outages (N=9,784)

Outcome variables	Outage (hours/day)				
	0-5 (8.7%)	**6-10 (58.7%)**	**11-15 (21.2%)**	**16-20 (6.2%)**	**>=21 (5.2%)**
HH kerosene consumption (liter/month)	1.89	1.99	1.79	1.97	3.18
	(1.13)	(1.21)	(1.30)	(1.60)	(2.18)
Per capita total income (Tk./month)	1,705.5	1,871.3	1,656.7	1,584.8	1,396.6
	(1,391.3)	(2,219.2)	(1,994.1)	(1,408.7)	(1,902.1)
Per capita firm income (Tk./month)	467.5	552.6	540.0	448.9	435.1
	(793.4)	(1,212.7)	(1,113.3)	(818.6)	(696.0)
Per capita nonfarm income (Tk./month)	1,238.0	1,318.6	1,116.8	1,135.9	961.5
	(1,074.3)	(1,298.9)	(1,198.5)	(948.8)	(1,795.7)
Per capita total expenditure (Tk./month)	1,009.9	997.5	1,066.3	1,062.2	921.2
	(443.1)	(395.6)	(458.4)	(456.5)	(484.3)
Per capita food expenditure (Tk./month)	632.6	641.7	687.1	705.3	626.6
	(242.1)	(237.5)	(264.4)	(266.4)	(237.6)
Per capita nonfood expenditure (Tk./month)	377.3	355.8	379.2	356.9	294.6
	(288.7)	(246.7)	(309.8)	(296.1)	(374.3)
Time spent in studies by boys (hours/day)	2.35	2.50	2.33	2.22	1.89
	(1.08)	(2.24)	(2.17)	(2.09)	(1.99)
Time spent in studies by girls (hours/day)	2.62	2.67	2.55	2.40	2.03
	(2.14)	(2.10)	(2.15)	(2.09)	(1.93)
Men’s labor force participation (%)	68.5	67.6	66.9	65.9	65.4
	(14.5)	(15.1)	(13.3)	(12.2)	(14.2)
Women’s labor force participation (%)	34.6	31.5	31.3	31.1	29.7
	(42.5)	(39.8)	(41.1)	(41.0)	(38.7)
Women have income generation activities (%)	13.8	11.3	7.5	11.3	7.9
	(34.5)	(31.7)	(26.3)	(31.6)	(26.9)
Women’s time spent in watching TV or listening to radio (minutes/day)	22.0	27.1	15.1	20.0	7.2
	(22.3)	(34.5)	(23.1)	(19.5)	(15.4)
Women can decide alone on children’s healthcare (%)	26.9	22.8	22.5	24.8	23.2
	(14.6)	(15.6)	(12.1)	(15.5)	(11.1)
Women can decide alone on the use of own income (%)	53.7	56.2	49.9	52.3	49.3
	(57.2)	(60.1)	(55.4)	(50.6)	(53.1)

Note: Standard deviations are reported in parentheses.
Source: BREB household survey, 2005

Table 5 Household and individual outcomes by duration of grid connection (N=4,080)

Outcome variables	Duration (years)				
	<=1 (4.9%)	**2-5 (32.2%)**	**6-10 (23.4%)**	**11-15 (17.6%)**	**>=16 (21.9%)**
HH kerosene consumption (liter/month)	2.16	1.98	1.69	1.82	1.76
	(2.02)	(2.68)	(1.39)	(1.53)	(1.43)
Per capita total income (Tk./month)	1,708.4	2,255.5	2,372.7	2,345.8	2,880.1
	(1,537.1)	(3,565.3)	(5,882.3)	(4,281.3)	(5,138.2)
Per capita firm income (Tk./month)	657.3	522.6	482.0	486.9	479.7
	(982.0)	(946.5)	(1.031.9)	(1,052.4)	(1,206.0)
Per capita nonfarm income (Tk./month)	1,051.1	1,732.9	1,890.7	1,858.9	2,400.4
	(1,353.0)	(2,478.9)	(4,746.6)	(4,141.5)	(4,996.8)
Per capita total expenditure (Tk./month)	1,038.9	1,055.2	1,224.0	1,423.4	1,394.0
	(809.2)	(813.9)	(2,817.5)	(4,478.7)	(1,594.0)
Per capita food expenditure (Tk./month)	556.9	597.5	619.1	646.1	666.3
	(238.1)	(248.8)	(272.6)	(278.0)	(312.8)
Per capita nonfood expenditure (Tk./month)	482.0	457.7	604.9	777.2	727.7
	(710.1)	(712.2)	(2,756.9)	(4,444.3)	(1,482.3)
Time spent in studies by boys (hours/day)	2.22	2.38	2.26	2.51	2.36
	(1.61)	(1.71)	(1.75)	(1.74)	(1.80)
Time spent in studies by girls (hours/day)	1.89	2.33	2.27	2.44	2.62
	(1.70)	(1.76)	(1.76)	(1.75)	(1.98)
Men’s labor force participation (%)	71.2	71.7	72.6	75.3	79.0
	(48.5)	(64.9)	(53.8)	(69.8)	(60.6)
Women’s labor force participation (%)	30.8	33.1	40.9	45.3	47.6
	(31.2)	(24.3)	(35.8)	(41.9)	(42.8)
Women have income generation activities (%)	17.6	20.2	21.2	22.9	23.1
	(9.2)	(14.5)	(15.4)	(17.7)	(20.1)
Women’s time spent in watching TV or listening to radio (minutes/day)	45.8	59.4	67.8	68.2	67.7
	(56.7)	(60.4)	(76.9)	(86.9)	(81.3)
Women can decide alone on children’s healthcare (%)	81.6	83.1	82.2	83.1	82.5
	(38.8)	(37.7)	(38.3)	(37.5)	(38.0)
Women can decide alone on the use of own income (%)	85.3	89.2	88.2	83.1	88.5
	(35.5)	(33.2)	(32.2)	(37.5)	(32.0)

Note: Standard deviations are reported in parentheses.
Source: BREB household survey, 2010

Table 6 Household appliance ownership by duration of grid connection (%) (N=4,080)

Appliances	Duration (years)				
	<=1 (4.9%)	**2-5 (32.2%)**	**6-10 (23.4%)**	**11-15 (17.6%)**	**>=16 (21.9%)**
Electric fan	32.6	41.7	38.6	47.8	55.2
	(67.3)	(76.4)	(87.8)	(91.3)	(98.7)
Radio	6.4	6.9	7.3	9.6	11.5
	(16.5)	(15.9)	(25.8)	(32.1)	(41.1)
B/W YV	27.7	29.6	33.3	30.9	26.7
	(44.9)	(45.7)	(47.1)	(46.2)	(44.3)
Color TV	27.2	31.3	47.7	53.5	58.0
	(44.7)	(46.4)	(58.5)	(61.3)	(72.5)
Refrigerator	4.4	8.1	18.2	25.5	36.6
	(20.7)	(27.4)	(33.8)	(51.8)	(65.7)
Computer	0.8	0.7	1.2	1.6	2.1
	(9.2)	(8.2)	(11.2)	(12.5)	(14.5)
A/C	0	0.04	0.2	0.4	0.6
	(-)	(2.1)	(4.7)	(6.1)	(8.2)

Note: The summary statistics are based on RERED household survey in 2010. Standard deviations are reported in parentheses.
Source: BREB household survey 2010

Table 7 Effects of electrification and power outages
(N=10,760)

Outcome variable	**(1) Village fixed-effects estimates**	**(2) Village fixed-effects with IV estimates)**	**(3) Aggregate effects of electrification based on (2)**
Consumption of traditional fuel			
Log HH kerosene consumption (liter/month)			
Household has grid electricity	-0.813**	-0.894**	-0.733**
	(-16.81)	(-13.12)	(-6.96)
Household has grid electricity X Duration of power outage (hours/day)	0.001	0.059**	
	(0.42)	(2.47)	
Economic Outcomes			
Log per capita total income (Tk./month)			
Household has grid electricity	0.205**	0.211**	0.171**
	(11.90)	(8.06)	(2.17)
Household has grid electricity X Duration of power outage (hours/day)	-0.001	-0.003**	
	(-0.59)	(-2.06)	
Log per capita farm income (Tk./month)			
Household has grid electricity	0.351**	0.435	0.246
	(4.08)	(0.23)	(0.28)
Household has grid electricity X Duration of power outage (hours/day)	-0.007	-0.029	
	(-1.23)	(-0.11)	
Log per capita nonfarm income (Tk./month)			
Household has grid electricity	0.445**	0.341**	0.248
	(5.94)	(2.01)	(1.54)
Household has grid electricity X Duration of power outage (hours/day)	0.004	-0.006*	
	(0.72)	(-1.93)	
Log per capita total expenditure (Tk./month)			
Household has grid electricity	0.112**	0.144*	0.115*
	(8.82)	(1.75)	(1.66)
Household has grid electricity X Duration of power outage (hours/day)	0.001	-0.005	
	(0.89)	(-1.29)	
Log per capita food expenditure (Tk./month)			
Household has grid electricity	0.055**	0.075	0.059
	(4.14)	(0.57)	(0.64)
Household has grid electricity X Duration of power outage (hours/day)	0.001	-0.008	
	(0.56)	(-0.42)	
Log per capita nonfood expenditure (Tk./month)			

Outcome variable	(1) Village fixed-effects estimates	(2) Village fixed-effects with IV estimates)	(3) Aggregate effects of electrification based on (2)
Household has grid electricity	0.275**	0.347**	0.207**
	(14.32)	(6.22)	(2.36)
Household has grid electricity X Duration of power outage (hours/day)	0.0004	-0.008*	
	(0.30)	(-1.91)	
Education Outcomes			
Time spent on studies by boys (hours/day)			
Household has grid electricity	0.329**	0.819	0.399
	(4.44)	(0.40)	(0.28)
Household has grid electricity X Duration of power outage (hours/day)	0.0002	-0.134	
	(0.03)	(0.66)	
Time spent on studies by girls (hours/day)			
Household has grid electricity	0.282**	0.585*	0.470*
	(3.76)	(1.93)	(1.89)
Household has grid electricity X Duration of power outage (hours/day)	0.003	-0.108**	
	(0.65)	(-2.02)	
Employment Outcomes (age 15-65)			
Men's labor force participation			
Household has grid electricity	-0.010	-0.149	-0.104
	(-1.09)	(-0.99)	(-1.01)
Household has grid electricity X Duration of power outage (hours/day)	0.0006	0.015	
	(1.11)	(0.94)	
Women's labor force participation			
Household has grid electricity	0.054**	0.058*	0.023*
	(3.37)	(1.68)	(1.63)
Household has grid electricity X Duration of power outage (hours/day)	-0.001	-0.007	
	(-1.21)	(-1.57)	
Women's Empowerment (age 15-49)			
Women operate income generation activities			
Household has grid electricity	0.035**	0.010	-0.0006
	(3.89)	(0.03)	(-0.001)
Household has grid electricity X Duration of power outage (hours/day)	-0.00005	-0.003	
	(-0.08)	(-0.10)	
Women's time spent on watching TV or listening to radio (minutes/day)			

Outcome variable	**(1) Village fixed-effects estimates**	**(2) Village fixed-effects with IV estimates)**	**(3) Aggregate effects of electrification based on (2)**
Household has grid electricity	39.7**	51.81*	48.07*
	(19.14)	(1.94)	(1.72)
Household has grid electricity X Duration of power outage (hours/day)	-4.30**	-5.25**	
	(-2.68)	(-2.44)	
Women can decide alone on children's healthcare			
Household has grid electricity	0.022**	0.043**	0.023**
	(2.25)	(2.23)	(2.21)
Household has grid electricity X Duration of power outage (hours/day)	-0.0009	-0.004**	
	(-0.72)	(-2.25)	
Women can decide alone on the use of own income			
Household has grid electricity	-0.007	0.064**	0.048*
	(-1.10)	(2.09)	(1.79)
Household has grid electricity X Duration of power outage (hours/day)	0.0004	-0.006**	
	(0.95)	(-2.10)	

Note: * and ** indicates statistical significance at 10 percent and 5 percent, respectively. Village fixed effects are controlled for but not reported. Figures in parentheses are t-statistics based on robust standard errors clustered at village level.

Table 8 Effects of electrification and duration of grid connection (N=7,018)

Outcome variable	(1) Fixed-effects	(2) Propensity score-weighted fixed-effects
Consumption of traditional fuel		
Log HH kerosene consumption (liter/month)		
Duration of electricity connection (years)	-0.077**	-0.078**
	(-3.94)	(-3.61)
Duration of electricity connection squared	0.002**	0.002**
	(2.00)	(2.17)
Log per capita total income (Tk./month)		
Duration of electricity connection (years)	0.011*	0.010*
	(1.77)	(1.68)
Duration of electricity connection squared	-0.0006**	-0.0005**
	(-2.40)	(-2.06)
Log per capita firm income (Tk./month)		
Duration of electricity connection (years)	-0.016	-0.001
	(-0.75)	(-0.06)
Duration of electricity connection squared	-0.003**	-0.004**
	(-3.82)	(-4.53)
Log per capita nonfarm income (Tk./month)		
Duration of electricity connection (years)	0.043**	0.041**
	(2.18)	(2.06)
Duration of electricity connection squared	-0.001	-0.0004
	(-1.27)	(-0.60)
Log per capita total expenditure (Tk./month)		
Duration of electricity connection (years)	0.010**	0.011**
	(2.74)	(3.00)
Duration of electricity connection squared	-0.0004	-0.0001
	(-0.30)	(-0.98)
Log per capita food expenditure (Tk./month)		
Duration of electricity connection (years)	0.007*	0.008*
	(1.88)	(1.97)
Duration of electricity connection squared	-0.0003*	-0.0003*
	(-1.88)	(-1.94)
Log per capita nonfood expenditure (Tk./month)		
Duration of electricity connection (years)	0.022**	0.023**
	(3.59)	(3.73)
Duration of electricity connection squared	-0.0001	-0.0002
	(-0.31)	(-1.05)

Outcome variable	**(1)** **Fixed-effects**	**(2)** **Propensity score-weighted fixed-effects**
Time spent in studies by boys (hours/day)		
Duration of electricity connection (years)	0.050**	0.041*
	(2.16)	(1.70)
Duration of electricity connection squared	-0.002*	-0.001
	(-1.80)	(-1.31)
Time spent in studies by girls (hours/day)		
Duration of electricity connection (years)	0.051**	0.049*
	(2.02)	(1.66)
Duration of electricity connection squared	-0.001	-0.002
	(-1.20)	(-1.28)
Men's labor force participation		
Duration of electricity connection (years)	0.001	-0.001
	(0.22)	(-0.19)
Duration of electricity connection squared	-0.0003**	-0.0002*
	(-3.04)	(-1.81)
Women's labor force participation		
Duration of electricity connection (years)	-0.001	-0.002
	(-0.26)	(-0.55)
Duration of electricity connection squared	-0.0005**	-0.0004**
	(-4.17)	(-2.66)
Women operate income generation activities		
Duration of electricity connection (years)	0.001	-0.001
	(0.12)	(-0.21)
Duration of electricity connection squared	0.0002	0.0002
	(0.92)	(1.09)
Women's time spent in watching TV or listening to radio (minutes/day)		
Duration of electricity connection (years)	2.43**	2.83**
	(4.64)	(4.92)
Duration of electricity connection squared	-0.225**	-0.222**
	(-9.91)	(-9.08)
Women can decide alone on children's healthcare		
Duration of electricity connection (years)	0.006	0.005
	(1.40)	(1.27)
Duration of electricity connection squared	-0.00004	-0.00006
	(-0.27)	(-0.36)
Women can decide alone on the use of own income		
Duration of electricity connection (years)	0.007	0.008*

Outcome variable	(1) Fixed-effects	(2) Propensity score-weighted fixed-effects
	(1.33)	(1.68)
Duration of electricity connection squared	-0.00004	-0.0001
	(-0.17)	(-0.66)

Note: * and ** indicates statistical significance at 10 percent and 5 percent, respectively. Village fixed- effects are controlled for but not reported. Figures in parentheses are t-statistics based on robust standard errors clustered at village level.

Table 10 Heterogeneous effects of electrification given duration of grid connection (N=7,018)

Outcome variable	Lower bound (duration=1 year)	Upper bound (duration=10 years)
Log HH kerosene consumption (liter/month)	-0.077**	-0.602**
Log per capita total income (Tk./month)	0.009*	0.045*
Log per capita farm income (Tk./month)	-0.005	-0.400
Log per capita non-farm income (Tk./month)	0.040**	0.363**
Per capita total expenditure (Tk./month)	0.011**	0.100**
Log per capita food expenditure (Tk./month)	0.007*	0.048*
Log per capita nonfood expenditure (Tk./month)	0.023**	0.209*
Time spent in studies by boys (hours/day)	0.039*	0.277*
Time spent in studies by girls (hours/day)	0.047*	0.330*
Men’s labor force participation	-0.001	-0.030
Women’s labor force participation	-0.002	-0.060
Women operate income generation activities	-0.0001	0.011
Women’s time spent in watching TV or listening to radio (minutes/day)	2.61**	6.13**
Women can decide alone on children’s healthcare	0.005	0.046
Women can decide alone on the use of own income	0.008*	0.069*

Note: This table summarizes the range of electrification effects by varying duration of grid connection. The prediction is based coefficients reported in column (2) of Table 8. * and ** indicates statistical significance at 10 percent and 5 percent, respectively.

Table 10 Household FE quantile regression estimates of electrification impacts on income and expenditure
(N=7,018)

Quantiles	Log per capita income (Tk./month)	Log per capita expenditure (Tk./month)
20th	0.025	0.038*
	(0.77)	(1.77)
40th	0.046	0.046**
	(1.39)	(2.05)
60th	0.063*	0.047*
	(1.96)	(1.82)
80th	0.086*	0.106**
	(1.92)	(3.34)

Note: * and ** indicates statistical significance at 10 percent and 5 percent, respectively. Figures in parentheses are t-statistics based on robust standard errors clustered at village level.

Annex

Table A1 Summary of effects of rural electrification reported in the literature

Outcomes	Findings	Country	Years of observation	Source
Employment	Female employment rises 9 to 9.5 percentage points. Women work 8.9 hours more and men work 13 hours more per week in areas with higher electrification rates.	South Africa	1995-2001	Dinkelman (2011)
	17–18 percentage point increase in the probability of employment.	Brazil	1960-2000	Lipscomb et al (2013)
	Additional 14.6 days per year of regular wage work for men.	India	1982-1999	Van de Walle et al (2015)
Income/ Expenditure	10 percent increase in electrification increases income per capita increases by almost 10 percent.	Brazil	1960-2000	Lipscomb et al (2013)
	Gain in total income is as high as 21 percent. Household per capita expenditure increases by 11.3 percent.	Bangladesh	2005	Khandker et al (2012)
	Increase in non-farm income as high as 76%	Bhutan	2010	Kumar and Rauniyar (2011)
Income/ Expenditure Education	Village causes annual household expenditures to increase by 38 percent. Similarly, total household income increases by nearly 42 percent.	Philippines	2003-2014	Chakravorty et al (2016)
	"Internal" consumption gain of 0.5% per year, and "external" consumption gain of 0.8% per year.	India	1982-1999	Van de Walle et al (2015)
	Increases years of schooling by 2 years.	Brazil	1960-2000	Lipscomb et al (2013)
Education	Completed schooling years increases by 0.233 grade for boys and 0.157 grade for girls. Boys' study time increased by almost 22 minutes a day and girls' by 12 minutes a day.	Bangladesh	2005	Khandker et al (2012)
	Children in electrified households have 0.75 additional years of schooling. Amount of evening study time at home is 10 minutes more.	Bhutan	2010	Kumar and Rauniyar (2011)

Table A2 Panel estimation of the effects of electrification without the square term of time span of connection (N=7,018)

Outcome variable	Fixed-effects	Propensity score-weighted fixed-effects
Log HH kerosene consumption (liter/month)		
Duration of electricity connection (years)	-0.049**	-0.047**
	(-4.04)	(-3.76)
Log per capita total income (Tk./month)		
Duration of electricity connection (years)	0.012*	0.001
	(1.71)	(0.16)
Log per capita firm income (Tk./month)		
Duration of electricity connection (years)	-0.074	-0.068
	(-1.15)	(-1.43)
Log per capita nonfarm income (Tk./month)		
Duration of electricity connection (years)	0.028**	0.033**
	(2.09)	(2.45)
Log per capita total expenditure (Tk./month)		
Duration of electricity connection (years)	0.009**	0.009**
	(3.73)	(3.54)
Log per capita food expenditure (Tk./month)		
Duration of electricity connection (years)	0.002	0.003
	(0.83)	(1.06)
Log per capita nonfood expenditure (Tk./month)		
Duration of electricity connection (years)	0.021**	0.019**
	(4.95)	(4.37)
Time spent in studies by boys (hours/day)		
Duration of electricity connection (years)	0.020**	0.018*
	(2.38)	(1.78)
Time spent in studies by girls (hours/day)		
Duration of electricity connection (years)	0.029*	0.022*
	(1.77)	(1.69)
Men’s labor force participation		
Duration of electricity connection (years)	-0.006	-0.005
	(-0.97)	(-1.00)
Women’s labor force participation		
Duration of electricity connection (years)	-0.010	-0.009
	(-1.01)	(-0.75)
Women operate income generation activities		
Duration of electricity connection (years)	0.003	0.003
	(1.21)	(0.96)

Outcome variable	**Fixed-effects**	**Propensity score-weighted fixed-effects**
Women's time spent in watching TV or listening to radio (minutes/day)		
Duration of electricity connection (years)	1.53**	1.83**
	(3.93)	(4.15)
Women can decide alone on children's healthcare		
Duration of electricity connection (years)	0.005*	0.004
	(1.69)	(1.46)
Women can decide alone on the use of own income		
Duration of electricity connection (years)	0.006*	0.006*
	(1.76)	(1.69)

Note: * and ** indicates statistical significance at 10 percent and 5 percent, respectively. Village fixed effects are controlled for but not reported. Figures in parentheses are t-statistics based on robust standard errors clustered at village level.